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ANALYSIS OF VARIANCE OF PHOTOGRAPHIC AND VISUAL ESTIMATES OF DOLPHIN SCHOOL SIZE

by

William G. Clark

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ANALYSIS OF VARIANCE OF PHOTOGRAPHIC AND
VISUAL ESTIMATES OF DOLPHIN SCHOOL SIZE

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ABSTRACT

In the years 1979-81, the sizes of 71 schools of small cetaceans were estimated both photographically and visually. The photo estimates include results from different readers of the same photographs, different cameras, and successive passes over some schools. The visual estimates include values from different observers.

This paper presents a statistical analysis of the data. Camera format and pass were both found to have significant effects on photo estimates, but the effects were so small relative to the variation in school size as to be negligible. The relationship between visual estimates and photo estimates was found to vary significantly among observers, and this effect was large (on the order of tens of percent of school size). These differences among observers precluded any single relationship for adjusting the visual estimates of the schools not photographed.

An attempt was made to determine a predictive relationship between visual and photo estimates for each observer that took part in the 1979 aerial survey, so that at least the 1979 population estimate could be adjusted. Owing to the size distribution of the schools photographed in that year, however, this was not possible.

1. INTRODUCTION

In the years 1979-81, a number of schools of small cetaceans (mainly dolphins of the genera Stenella and Delphinus in single-species or mixed schools) were photographed from aircraft with various kinds of cameras for the purpose of obtaining reliable counts of the number of animals in each school.

Usually the aircraft made several passes over a school, and on each pass the school was photographed with one or two kinds of camera. Over the years a total of four basic camera types were used at one time or another:

- (i) A relatively old 9" aerial mapping camera (K-17C) used in 1979. (9" refers to frame size, in this case 9"x 9".)
- (ii) A newer 9" camera (T-12) used in 1980.
- (iii) A 5" maritime surveillance camera (KA-62A) used in 1980 and 1981.
- (iv) Hasselblad 2 $\frac{1}{4}$ " cameras used in all three years.

Later the photographs were developed and reviewed. Some were omitted at this point as defective in some way (e.g., a portion of the school may not have been photographed or may have been obscured by glare). The animals in all other photographs were counted, almost always by two or more readers independently. In estimating the number of animals in a school, the readers usually made a small upward adjustment (typically a few percent)

to account for uncertain images in the photographs. The so-called "best estimates" from each such reading are shown in Table 1 for all photographs judged to be successful.

Many schools sighted during aerial surveys were not photographed successfully, or were not photographed at all. Their size was, however, estimated visually by observers in the survey aircraft. Table 2 shows the independent visual estimates of the schools with photo estimates in Table 1.

At this point there are a number of questions about the photo and visual estimates of school size. This paper aims to deal with those questions that can be answered by statistical analysis of the data themselves, such as:

(i) Do photographs taken with the same camera on successive passes over the same school yield statistically indistinguishable estimates of school size?

(ii) Do the different camera types yield different school size estimates?

(iii) Are there systematic differences among observers in visual estimates?

(iv) Can the large number of visual estimates be calibrated by the photo estimates of those schools for which both kinds of estimates are available?

The last question is particularly important for the 1979 aerial survey, which produced a population estimate based primarily on visual estimates. Special consideration will be given to the possibility of calibrating those visual estimates with the photo estimates obtained in 1979.

2. ANALYSIS OF VARIANCE OF PHOTO ESTIMATES

Not surprisingly, the within-cell variance of the photo estimates (i.e., the variance among readings of the same photograph) is larger for large schools than small ones. This suggests a similar proportional error variance, or coefficient of variability, at different school sizes, which in turn suggests a logarithmic transformation to standardize the within cell variances. Bartlett's test did not show significant heterogeneity of variances in the logarithms of the photo estimates, so these were used in all the analyses. Roughly speaking, of course, a difference between cells in the logarithms of the estimates can be regarded as a proportional difference. Thus a logarithmic difference of .05 is about the same as a 5% difference in estimated school size.

2.1 Sources of variance

The variance among the photo estimates in Table 1 comes from several sources:

(i) Reading. Different readers usually obtained different estimates from a single photograph. These differences among readings of the same photograph measure the minimum uncertainty inherent in the method. For purposes of variance analysis, they provide the within-cell variance with which other effects are compared.

(ii) Format. There may or may not be a significant difference, on average, between estimates based on photographs taken with different camera formats (camera types) on the same passes over the same schools. This can be tested.

(iii). Pass. There may or may not be a significant difference, on average, between estimates based on photographs taken with the same camera on different passes over the same school. This can be tested.

(iv) School. There are obviously large differences among schools in estimates of school size, and these are quite consistent among passes and formats. While there is no doubt that the effect of school is large and significant, this factor necessarily appears in all the variance analyses so that it can be estimated and then removed to test those effects that are in question--pass and format.

2.2 The linear model

Algebraically, the effect of various factors on the logarithmic estimates is represented as:

$$y_{ijkn} = \mu + a_i + b_{ij} + \gamma_k + (a\gamma)_{ik} + (b\gamma)_{ijk} + \epsilon_{ijkn}$$

where y_{ijkn} = log estimate by reader n of the size of school i, photographed on pass j with camera format k.

μ = mean log school size

a_i = effect of school i (that is, its deviation from the mean)

b_{ij} = effect of pass j (that is, the deviation of pass j estimates from the mean of the estimates of school i. This factor is denoted b_{ij} because it is nested within school.)

γ_k = effect of camera format k

$(a\gamma)_{ik}$ = school-format interaction

$(b\gamma)_{ijk}$ = pass-format interaction (these interactions could be significant if the performance of a given camera format depended on, for example, school size or transient light conditions).

ϵ_{ijkn} = error in a single reading.

In terms of the analysis of variance, this is a mixed model with nesting: camera format γ_k is treated as a fixed effect to be tested for significance and estimated if found significant, while school a_i and pass b_{ij} are treated as random effects with pass nested within school. The effect of school is obviously significant, but the effect of pass needs to be tested. This amounts to testing whether photo estimates of school size are repeatable apart from differences among readers.

To test all the effects in the model would require at least some data for all combinations of all factors, but Table 1 shows that there are some very large gaps in the data. In fact, only for schools photographed on multiple passes in 1980 with both the 9" and 5" cameras is there an opportunity to treat the effects of school, pass, format, and reading simultaneously. Meanwhile both the 2 $\frac{1}{4}$ " camera and the 9" camera used in 1979 are, with few exceptions, limited to passes where only one or the other was used, so the effects of pass and format are confounded. This would not be a problem if the effect of pass turned out not to be significant, so that pass could be eliminated from the model. For this reason the first step in the analysis was to investigate the effect of pass.

2.3 Effect of pass within formats

In order to use as much of the data as possible, an analysis of variance was done for each camera format separately. Treating the formats separately for this purpose also simplified the model, since only school, pass, and reading remained as sources of variance. The analysis for each camera format took in the estimates of all schools with at least two readings from each of at least two passes when the camera in question was operated. The 9" camera used in 1979 could not be treated at all because it was not operated successfully on more than one pass over any school.

For the other three formats, the variance analyses (Table 3) showed that the effect of pass was highly significant. Root variance components were estimated as:

	<u>9" camera (1980)</u>	<u>5" camera</u>	<u>2$\frac{1}{4}$" camera</u>
School	.758	1.200	.933
Pass	.081	.071	.057
Reading	.053	.045	.047

Thus while the effect of pass is significant, it is not large, at 6-8% of school size barely exceeding the variation due to reading, which is close to 5% of school size for all three formats. School accounts for about 99% of the total variance in all three sets of data.

Since an aircraft making repeated passes over a school affects the behavior of the animals, pass can be treated as a covariate instead of as a variance component (Table 4). When it is, the slope is positive and significant within each camera format, which means there is a significant tendency for photo estimates to increase on succeeding passes:

	<u>9" camera (1980)</u>	<u>5" camera</u>	<u>2$\frac{1}{4}$" camera</u>
Estimated slope	.018	.011	.038
95% confidence interval	(.004-.032)	(.003-.020)	(.012-.064)

Once again it should be noticed that while the effect is significant it is small, amounting to 1-2% of school size per pass.

2.4 Effect of pass among formats

Since pass turned out to be significant within each format, it could not be eliminated from the model. The way in which it was handled

thereafter, however, depended on the nature of the effect. There were two possibilities at the extremes:

(i) The effect of pass was consistent among formats. In terms of the model, the effect is that of b_{ij} rather than of $(a\gamma)_{ij}$ or $(b\gamma)_{ijk}$. In this case it would not be possible to compare estimates obtained with different formats on different passes, since the effects of pass and format would be confounded.

(ii) The effect of pass was not consistent among formats. [In terms of the model the effect is that of the interaction terms $(a\gamma)_{ij}$ and $(b\gamma)_{ijk}$ rather than b_{ij} .] In this case it would be possible to compare estimates obtained with different formats on different passes since for purposes of testing the effect of format, the effect of pass would simply add to the error variance.

Since pass was significant as a covariate within each format, the first possibility was not to be excluded altogether. In order to decompose the effect of pass into a consistent portion and a residual representing interaction, an analysis of variance was done on only those schools that permitted all effects to be estimated simultaneously, namely the schools photographed in 1980 with both the 5" and 9" cameras on at least two passes (a total of 11 schools). This analysis (Table 5) showed that both portions were significant, but that the consistent effect of pass accounted for three quarters of the variance associated with pass. The effect of pass was therefore found to be largely consistent among formats, and the interaction terms unimportant.

2.5 Effect of format

Since the effect of pass turned out to be consistent among formats, the only good test of format was restricted to passes on which at least

two cameras were operated successfully. This requirement effectively restricted the comparison to the same set of 11 schools referred to above, namely, the ones photographed in 1980 with both the 5" and 9" cameras on the same passes. In the analysis of variance of those estimates reported above, format was significant as a fixed effect ($P = .04$), but again the effect was small, .015. This means that on the average the 9" estimates were 1.5% greater than the 5" estimates in 1980.

While data are lacking to estimate the effects of the 2 $\frac{1}{4}$ " camera and the 9" camera used in 1979, it does not appear possible that either could be large. For the few passes where one or the other was operated along with another camera, the readings are mostly similar. For the five schools photographed in 1981 with both the 5" camera and the 2 $\frac{1}{4}$ " camera, but on different passes, the estimates are often noticeably different, but the differences show the effect of pass as well as format, and in fact are largely what one would expect from the effect of pass alone, the later passes usually yielding higher estimates.

2.6 Conclusion

The analyses of variance of the photo estimates of school size showed that all possible sources are significant--school, format, pass, and interactions--but that the effect of school dwarfs all the rest of them.

For a particular school and format, the variance of an average photo estimate is, of course, smaller than the variance of a single photo estimate. In this situation, let

$$\begin{aligned} n_p &= \text{number of passes over the school} \\ n_r &= \text{number of readings per pass} \\ \sigma_p^2 \quad \sigma_r^2 &= \text{corresponding variance components of the log} \\ &\quad \text{estimate } y. \end{aligned}$$

$$V(\bar{y}) = \frac{\sigma_r^2}{n_r n_p} + \frac{\sigma_p^2}{n_p}$$

With $n_r = n_p = 2$, and with $\sigma_r = .05$ and $\sigma_p = .08$ as above, the standard deviation of the average photo estimate for a school is $S(\bar{y}) = .06$ or about 6% of school size. Therefore, even if differences due to camera format add a percentage point or two, the average photo estimate of school size is still very precise.

In what follows, the average photo estimate will be treated essentially as a fixed point, regardless of the format or number of passes involved, because the variance of photo estimates is so small compared with the variance of visual estimates. This procedure does not assume or require that the photo estimates are accurate. That is another question, outside the scope of this paper, but considered elsewhere (Allen et al. 1980, Perryman 1980).

3. ANALYSIS OF VARIANCE OF VISUAL ESTIMATES

The important question concerning visual estimates is whether there is a consistent relationship between visual and photographic estimates of a given school. If there is, the relationship can be used to adjust visual estimates of schools that were not photographed. If there is not, the interpretation of visual estimates is problematic.

The quantity of interest here is therefore not a visual estimate itself, but the difference between a visual estimate and the average photo estimate of the same school. For practical purposes this difference can be thought of as the error in the visual estimate, since the average photo estimate has a variance so much smaller than the variance of visual estimates

of a given school. (See Table 2.) Treating the difference as an error, of course, assumes that the bias of the average photo estimate is small or nil.

Like the photo estimates, the errors of the visual estimates have a variance that increases with school size. To standardize the variance, each visual estimate was divided by the average photo estimate of that school, and this ratio was used in all the analyses. Algebraically, this quantity is:

$$\begin{aligned} \text{ratio} &= \frac{\text{visual est.}}{\text{ave. photo est.}} \\ &= \frac{\text{ave. photo est.} + \text{error of visual est.}}{\text{ave. photo est.}} \\ &= 1 + \frac{\text{error of visual est.}}{\text{ave. photo est.}} \end{aligned}$$

Working with the ratio is therefore equivalent to working with the relative error of the visual estimate.

3.1 Sources of variance

A scatter diagram of all visual estimates and corresponding average photo estimates (Fig. 1) shows that despite some scatter, the visual estimates as a group are fairly accurate for small schools (up to 200 animals), but that the majority are low for larger schools. This suggests a curvilinear relationship between visual estimate and school size, with school size consequently accounting for some of the variance in the ratio (visual estimate)/(average photo estimate).

Another likely source of variance is the individual observer. That is, the scatter in Fig. 1 could represent a single relationship with a

large variance around it, or a flock of distinct relationships, one for each observer, with a smaller variance around each.

In summary, the sources of variance in the ratio are:

(i) School size. To categorize this effect, schools were divided into five size groups according to average photo estimates: 1-99, 100-199, 200-499, 500-999, and 1000+. These divisions were chosen because they provided a reasonably even distribution of schools among the five categories.

(ii) Observer. There are 13 observers in the data, but most are represented by rather few estimates (Table 2).

In addition, there may be a significant effect due to an individual school, but as this effect is not of interest, it will not be estimated. (I.e., in the analysis of variance, it will be left as part of the error term.)

3.2 The linear model

Algebraically, the model is:

$$r_{ijk} = \mu + \delta_i + \lambda_j + (\delta\lambda)_{ij} + \varepsilon_{ijk}$$

where r_{ijk} = the value of the ratio for school k in school size class j as estimated by observer i. (Note that k is simply an index of replicates--i.e., schools--within each cell. Even in the same school size category, the schools in different cells may be the same or different.)

μ = mean of the ratio among cells

δ_i = effect of observer i

λ_j = effect of school size category j

$(\delta\lambda)_{ij}$ = interaction (this would be important if there were differences among observers and the size of the differences varied among school size categories).

ϵ_{ijk} = random deviation of the estimate.

This is a two-way crossed classification. The only complication in the analysis is the data, which includes many empty cells and some observers whose estimates showed very large within-cell variances. Only a subset of the data--namely the values for observers 1, 2, and 3--was adequate in both coverage of cells and homogeneity of variance to carry out the analysis. The results below refer to this subset.

3.3 Results of the analysis

When the full subset was analyzed (Table 6), all factors (observer, school size, and interaction) were found to be highly significant, with mean ratios as follows:

<u>School size</u>	<u>Observer 1</u>	<u>Observer 2</u>	<u>Observer 3</u>
1-99	.96	.85	.70
100-199	.93	.84	.64
200-499	1.00	.66	.71
500-999	.88	.76	.49
1000+	.65	.45	.36

When only the first two school size categories were included in the analysis, school size was not significant, but observer and interaction were still highly significant. With only the first three school size categories in the analysis, school size was again highly significant.

Unlike pass and format in the case of visual estimates, the significant differences here are not small. Even within school size categories, the differences are not a few percent of school size but a few tens of percent.

In fact these results understate the differences among observers because the three observers in the subset analyzed all happened to estimate low on average. There were other observers who tended to estimate high, sometimes very high. In some school size categories, therefore, it seems likely that the average differences among some observers could amount to much more than the 10%-30% of school size that appears in the subset.

3.4 Conclusion

The interpretation of visual estimates is problematic. The analysis shows that both the location and the shape of the relationship between visual and photo estimates vary among observers, and vary widely. There remains the possibility of adjusting visual estimates observer by observer, but not of finding a common relationship, because there is none.

4. CONSIDERATION OF THE 1979 SURVEY

The analysis of the visual estimates described above was presented to an ad hoc meeting at the Southwest Fisheries Center in January 1983. In view of the results, the meeting decided that the best course was to calculate a relationship between visual and photo estimates for each observer that took part in the 1979 aerial survey, so that the visual school size estimates underlying the 1979 population estimate could be adjusted on an individual basis. The meeting further decided:

(i) Since the performance of individual observers may change over time, each relationship should be based only on schools photographed and estimated in 1979 (i.e., schools 1-15 in Tables 1 and 2).

(ii) In addition to the average photo estimate, a second kind of photo estimate of each school should be considered, namely the highest of the median readings determined for each pass and camera format. The reason for choosing the median rather than the average reading for each pass and format was to avoid outliers (wild readings); the reason for choosing the high median for each school was that lower values might represent missed animals rather than random error. For practical purposes these two kinds of photo estimates (average and high median) were nearly the same for schools photographed in 1979--in no case did the difference exceed 10%.

Of the fifteen schools photographed in 1979, thirteen contained 300 or fewer animals, one had about 1000, and one had about 2300. In the best case, therefore, the data available for fitting a relationship for a particular observer effectively consisted of three points--one clump near the origin and two others spotted across the range. These plots are shown in Figs. 2-7 for each observer in the 1979 data (except Observer 3, represented by only one value).

It is clear from the preceding section that the relationship between visual and photo estimates must be curvilinear, which suggests a function with two or three parameters. It is also clear that the variance about any predictive relationship must be large, and in absolute terms it must be much larger for large schools than for small ones.

The difficulty in obtaining any predictive relationship from the data at hand is that any of a variety of two- or three-parameter functions could be fitted to the "three" data points almost exactly, but the exercise would provide no realistic value for the error variance. As a consequence, it would not be possible to calculate a variance either for the parameter estimated or for the predicted photo estimates calculated from visual estimates.

To take an extreme example of the problem, look at the data points for Observer 5, who made some remarkable visual estimates. A curve fitted to these points would be nearly vertical at a visual estimate of 1500 or so. If there were a larger visual estimate from this observer, the corresponding predicted photo estimate would be stupendous. It would also be nonsense, the result of a large variance in visual estimates for which the 1979 data alone do not provide a measure.

In this situation, no further attempt was made to find a method of adjusting the visual estimates of schools that were not photographed.

ACKNOWLEDGEMENT

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Table 1

PHOTO ESTIMATES OF PORPOISE SCHOOL SIZE OBTAINED WITH VARIOUS CAMERA FORMATS

SCHOOL	PASS	9 INCH 1979 ---	9 INCH 1980-81	5 INCH -----	2+1/4 INCH -----
1	4	100 120 120			130 135 143
2	1	21 25 27			
3	1	16 17 18			
4	3	250 260 280			265 300 304
5	2	53 60 65			
6	1	100 104 120			90 110 120
6	2				
7	2	950 1050 1120			880 900 940
7	3				
8	1	2220 2275 2500			
9	1	61 64 67			
9	2				50 55 65
10	1	90 95 96			
11	2	70 71 74			
12	2	150 154 157			
13	1	105 113 138			
14	2	85 90 91			
14	3				
15	1	100 105 115			100 110 125
202	1		185 204	174 177	
202	2		158 170		
202	3		180 197		
204	1		217 223		203 220
204	2		219 229		
204	3		196 206	201 212	195 199 210 215
204	4		207 228	204 220	214 219 220 221
208	1		423 449 506	447 451	
209	1		426 459	437 442	
214	4		489 490	493 522	
214	7				

Table 1 (Cont'd.)

PHOTO ESTIMATES OF PORPOISE SCHOOL SIZE OBTAINED WITH VARIOUS CAMERA FORMATS					
SCHOOL	PASS	9 INCH 1979 ---	9 INCH 1980-81	5 INCH -----	2+1/4 INCH -----
217	1		24 24	23 25	
224	3				
224	5		173 177	170 179	184
224	7		129 131	168 175	
			153 165	170 171	
225	1				
225	2		54 65	67 69	
225	3		70 71	71 74	
			67 70	68 69	
226	1				
226	3		134 135	126 130	
226	4		143 144		
226	6			155 161	
226	7		145 146	138 147	
				129 140	
232	1				
232	2		206 215	182 205	
232	3		214 216	203 209	
232	4		204 234	204 217	
232	5		209 214	181 187	
232	6		207 222	211 213	
232	7		234 238	212 220	
			239 244	228 229	
235	1				
235	2		27 28	23 28	
				23 24	
238	2				
238	3		211 257	197 223	
238	4		205 207	198 201	
238	5		207 214	197 211	
238	6		212 245	203 206	
238	7		210 212	202 205	
238	8		203 209	208 210	
				196 203	
239	1				
239	2			74 74	
				73 74	
241	3			64 71	
244	1				
244	2		142 151	153 161	
244	3			157 161	
244	5			133 134	
244	6		127 146 161	171 181	
			179 189	147 164	
245	1				
245	3		653 673	622 627	
245	4		809 810	686 740	759
			802 806	751 755	

Table 1 (Cont'd.)

PHOTO ESTIMATES OF PORPOISE SCHOOL SIZE OBTAINED WITH VARIOUS CAMERA FORMATS

SCHOOL	PASS	9 INCH 1979 ---	9 INCH 1980-81	5 INCH -----	2+1/4 INCH -----
246	2		351 369	362 365	
246	3		361 369	354 380	
246	4		365 370	367 372	
246	5		379 386	395 404	
246	6		393 410	388 393	
247	1		247 247 251	246 248	
247	3		280 287	255 285	
247	4		224 224 245	228 253	
247	5		329 337		
248	2		723 777	712 720	
248	3		722 750	682 687	
248	5				
251	1		15 15	13 15	14 16
251	2				15 16
251	3			14 14	
254	2		56 59		
263	2		2216 2303	2097 2117	
263	5			1945 2098	
263	6		2468 2499	2552 2739	
263	10			1962 2172	
267	1			536 550	
267	2			497 561	
267	3			601 621	594
267	4			571 606	
267	5			579 583	
268	1			473 486	
268	2			434 492	
268	3			606 620	
268	4			494 521	
268	5			576 596	
270	1			1640 1797	
270	2			1526 1597	
270	3			1313 1383	
270	4			1476 1479	
270	5			1501 1536	
271	4			1870 1999	
272	2			345 357	
272	3			318 323	
					2026 2089 2012 2274 2115 2255

Table 1 (Cont'd.)

PHOTO ESTIMATES OF PORPOISE SCHOOL SIZE OBTAINED WITH VARIOUS CAMERA FORMATS

SCHOOL	PASS	9 INCH 1979 ---	9 INCH 1980-81	5 INCH -----	2+1/4 INCH -----
275	2			922 989	
277	2			146 153	
277	3			158 167	175
277	4			151 159	
278	2			53 56	
278	3			51 52	
280	3			789 795	
280	4			626 652	
280	5			663 693	
283	1			635 703	
283	2			915 947	
285	3			461 479	
285	5			429 477	
285	6			527 580	
286	3			469 485	
286	4			486 495	
287	3			6006 6261	
287	4			5683 6160	
288	1			1131 1216	
288	3			1244 1270	
290	2			1633 1749	
290	3			1684 1714	
290	4			1810 1834	
292	1		964	1023	
292	2		988	1029	
292	3			964 965	
293	2			921 957	
293	4			913 976	
293	5			852 859	
294	2			1853 1908	
294	4			2048 2200	
294	5			2030 2045	
295	4			2243 2303	
295	5			2268 2361	

Table 1 (Concluded)

PHOTO ESTIMATES OF PORPOISE SCHOOL SIZE OBTAINED WITH VARIOUS CAMERA FORMATS

SCHOOL	PASS	9 INCH 1979 ---	9 INCH 1980-81	5 INCH -----	2+1/4 INCH -----
299	5			768 803	
368	5			1282 1325 1493	
368	9			1083 1143	
401	1			455 460	
402	1			168 183	
501	1				332 358 362 365 401
501	2				311 316 335 338 367
501	3				351 392 395 400 411
502	1				47 49 59 59 63
503	1				76 76 79 80 90
504	1				183 185 189 190 192
504	2				184 186 190 190 192
504	3				
504	4				
505	1			171 171 192 208	
				191 193 204 216	
506	1				60 60 62 62 64
507	2			389 391 398 407	141 146 148 161 168
508	1				
508	2				114 119 120 123 123
508	3			125 126 127 128	130 133 134 136 142
508	4			125 125 126 127	
509	1			208 211 221 225	202 202 203 214 236
509	2				
510	1			146 160 168 170	134 135 137 146 154
510	2				
511	1			229 233 242 246	160 170 170 189 196
511	2				

Table 2. Average photo estimates and visual estimates of scoool size.

SCHOOL	AVERAGE PHOTO ESTIMATE	VISUAL ESTIMATES BY OBSERVERS												
		OBS 1	OBS 2	OBS 3	OBS 4	OBS 5	OBS 6	OBS 8	OBS 10	OBS 11	OBS 12	OBS 13	OBS 15	OBS 16
1	125	140			130	170	95	200						
2	24				28	35	40							
3	17				19	18	20	19						
4	277	210			1100	325	250	300						
5	59				80	165	80	120						
6	107	80			80	235	110	120	100					
7	973	900			1600	1540	1200	1000	1200					
8	2332	1100			2500	1500	2300	1500	1600					
9	60				130		110	250						
10	94						250	80						
11	72				75	102								
12	154	70			100		125	80	130					
13	119	100			130	200		140						
14	100	90			115		95		125					
15	107	85		45										
202	181	165	125	150										
204	213		125	200										
208	455	310	220	300										
209	441		225	250										
214	499		175	190										
217	24	20	28	23						32				
224	165	150	175							125				
225	68	50	50							40				
226	141	135	150	80						130				
232	214	285		175						275				

SCHOOL	AVERAGE PHOTO ESTIMATE	VISUAL ESTIMATES BY OBSERVERS													
		OBS 1	OBS 2	OBS 3	OBS 4	OBS 5	OBS 6	OBS 8	OBS 10	OBS 11	OBS 12	OBS 13	OBS 15	OBS 16	
235	26	30	22							20					
238	210	240	225												
239	74	60	35	40					90						
241	68	95	80						70						
244	156	130	140	130											
245	730	850	900												
246	377	550	450												
247	262	350	260	325					320						
248	722	1000	530	350					560						
251	15	15	14												
254	58	35	45	35											
263	2219	2100	900	1100											
267	573		300												
268	530		400												
270	1525		550												
271	1935		750												
272	336	175	120	135						150					
275	956	750	700							1000					
277	158	140	80	85						225					
278	53	42	38							45					
280	703		450	300						1000					
283	800		1200												
285	492	325	240	280											
286	484	275	230							450					
287	6028	4800	4200	2500						400					
										4000					

Table 3. ANOVA tables for log (photo estimate) within camera format;
pass treated as a nested factor.

9" camera (1980)

Source	SS	df	MS	F	P(F)
School	52.55	12	4.380	263.58	<.005
Pass within school	.57	35	.016	5.85	<.005
Reading	.15	52	.003		

5" camera

Source	SS	df	MS	F	P(F)
School	316.01	33	9.576	737.17	<.005
Pass within school	.92	73	.013	6.19	<.005
Reading	.24	120	.002		

2-1/4" camera

Source	SS	df	MS	F	P(F)
School	33.13	4	8.283	544.51	<.005
Pass within school	.11	7	.015	6.90	<.005
Reading	.08	37	.002		

Table 4. ANOVA tables for log (photo estimate) within camera format;
pass treated as a covariate.

9" camera (1980)

Source	SS	df	MS	F	P(F)
School	52.52	12	4.377	563.99	<.005
Pass	.05	1	.051	6.55	.012
Reading	.67	86			

5" camera

Source	SS	df	MS	F	P(F)
School	316.04	33	9.577	1638.86	<.005
Pass	.04	1	.038	6.46	.012
Reading	1.12	192	.006		

2-1/4" camera

Source	SS	df	MS	F	P(F)
School	31.04	4	7.760	2117.06	<.005
Pass	.03	1	.031	8.57	.005
Reading	.16	43	.004		

Table 5. ANOVA table for log (photo estimate) of the 11 schools photographed in 1980 with both the 5" and 9" cameras on at least two passes.

Source	SS	df	MS	F	P(F)
School	90.43	10	9.043	4029.39	<.005
Pass within school	.59	28	.021	9.39	<.005
Camera format	.01	1	.010	4.31	.041
Reading	.19	84	.002		

Table 6. ANOVA tables for the ratio (visual estimate)/(average photo estimate) for schools estimated by Observers 1, 2, and 3.

Case I: All schools included in the analysis

Source	SS	df	MS	F	P(F)
Observer	14.49	2	7.247	101.30	<.005
School size	3.41	4	.853	11.92	<.005
Interaction	57.21	9	6.357	88.85	<.005
Residual	7.58	106	.072		

Case II. Only schools <500 animals included in the analysis

Source	SS	df	MS	F	P(F)
Observer	13.02	2	6.511	82.59	<.005
School size	1.04	2	.518	6.57	<.005
Interaction	43.21	5	8.643	109.62	<.005
Residual	5.44	69	.079		

Case III. Only schools <200 animals included in the analysis

Source	SS	df	MS	F	P(F)
Observer	11.05	2	5.523	95.25	<.005
School size	.03	1	.027	.47	.496
Interaction	25.10	3	8.366	144.28	<.005
Residual	2.38	41	.058		

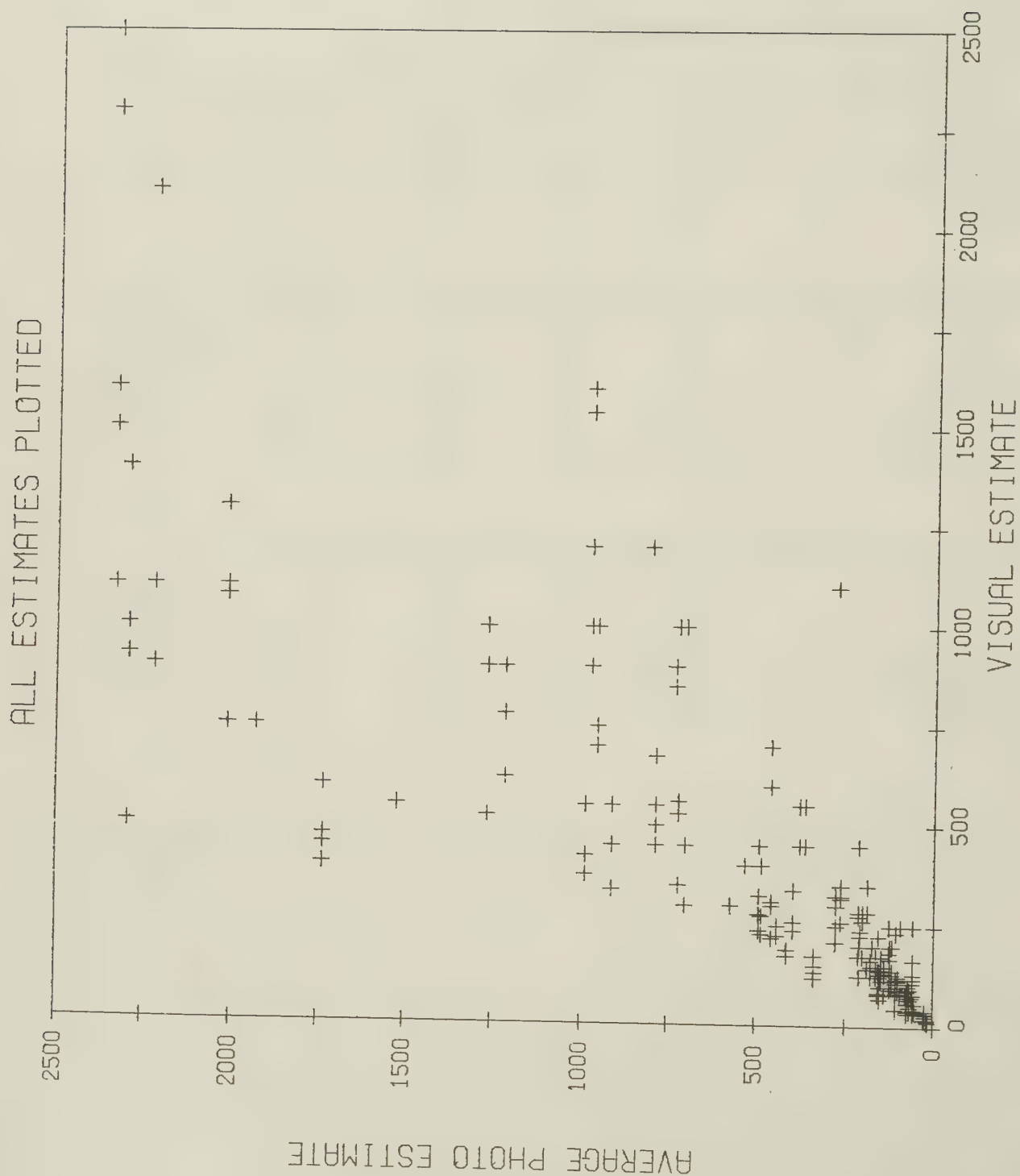


Figure 1. Average photo estimate plotted against visual estimates showing all schools except No. 287, which contained around 6000 animals.

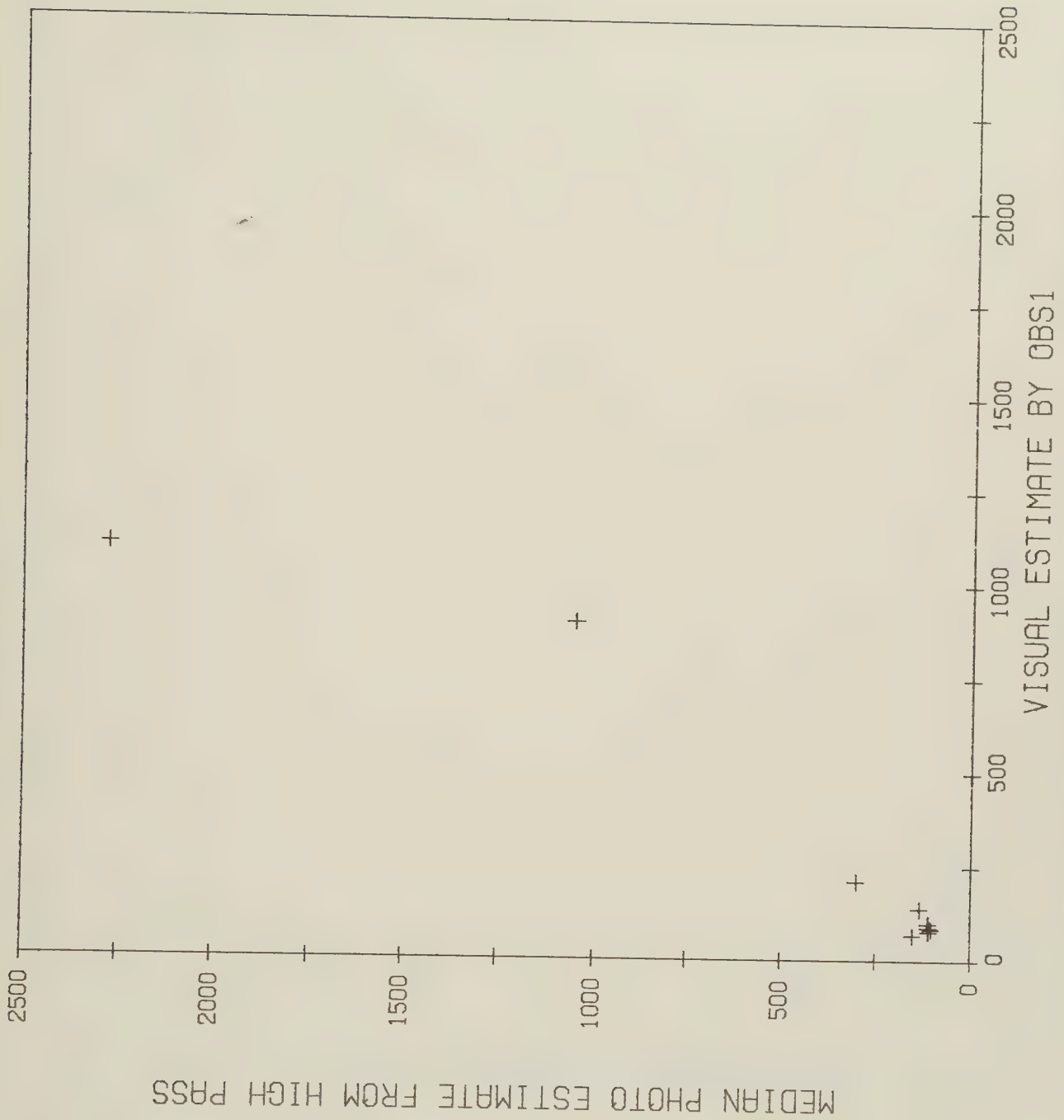


Figure 2. Visual estimates by Observer 1 in 1979 plotted against high median photo estimate.

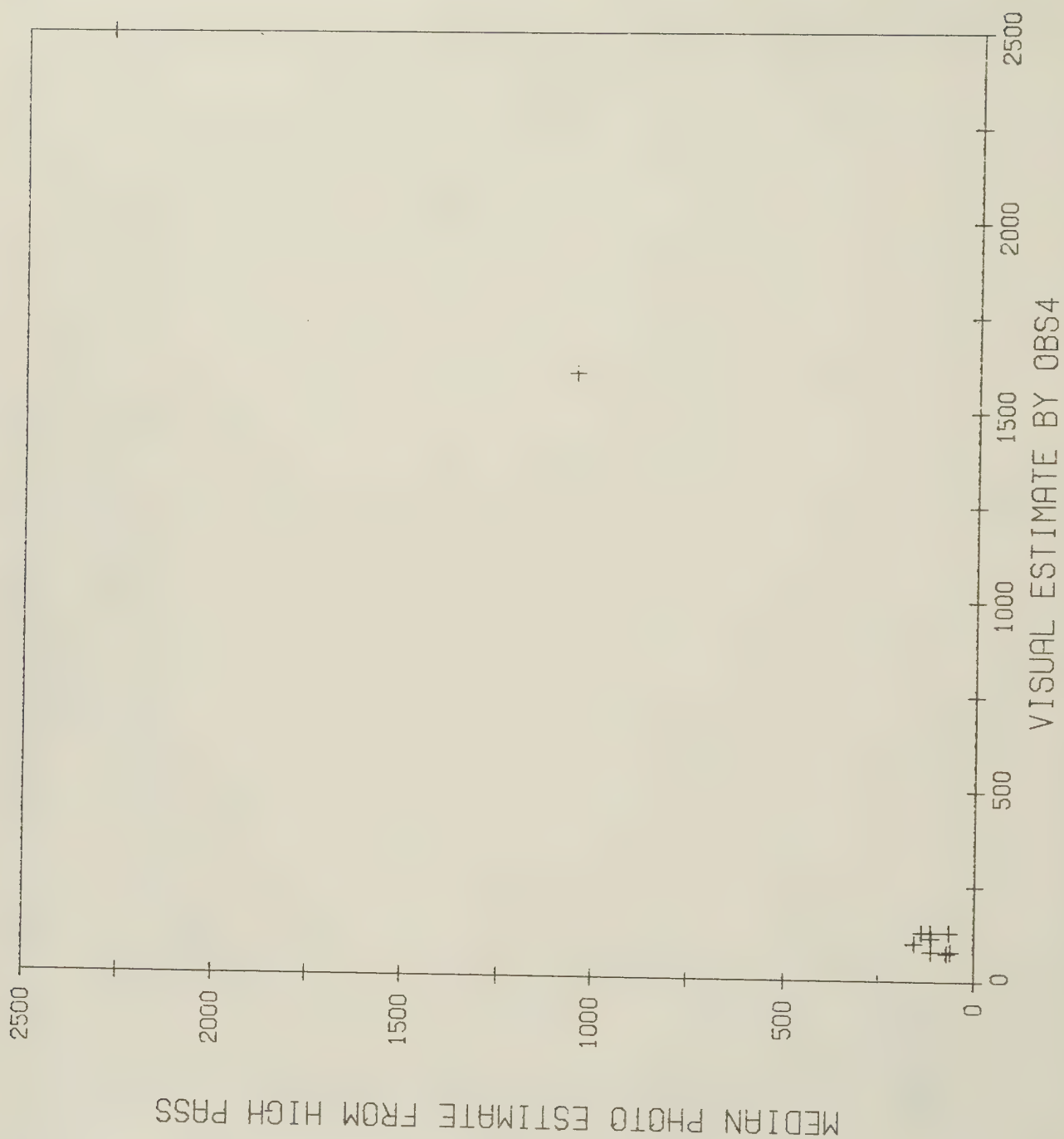


Figure 3. Visual estimates by Observer 4 in 1979 plotted against high median photo estimate.

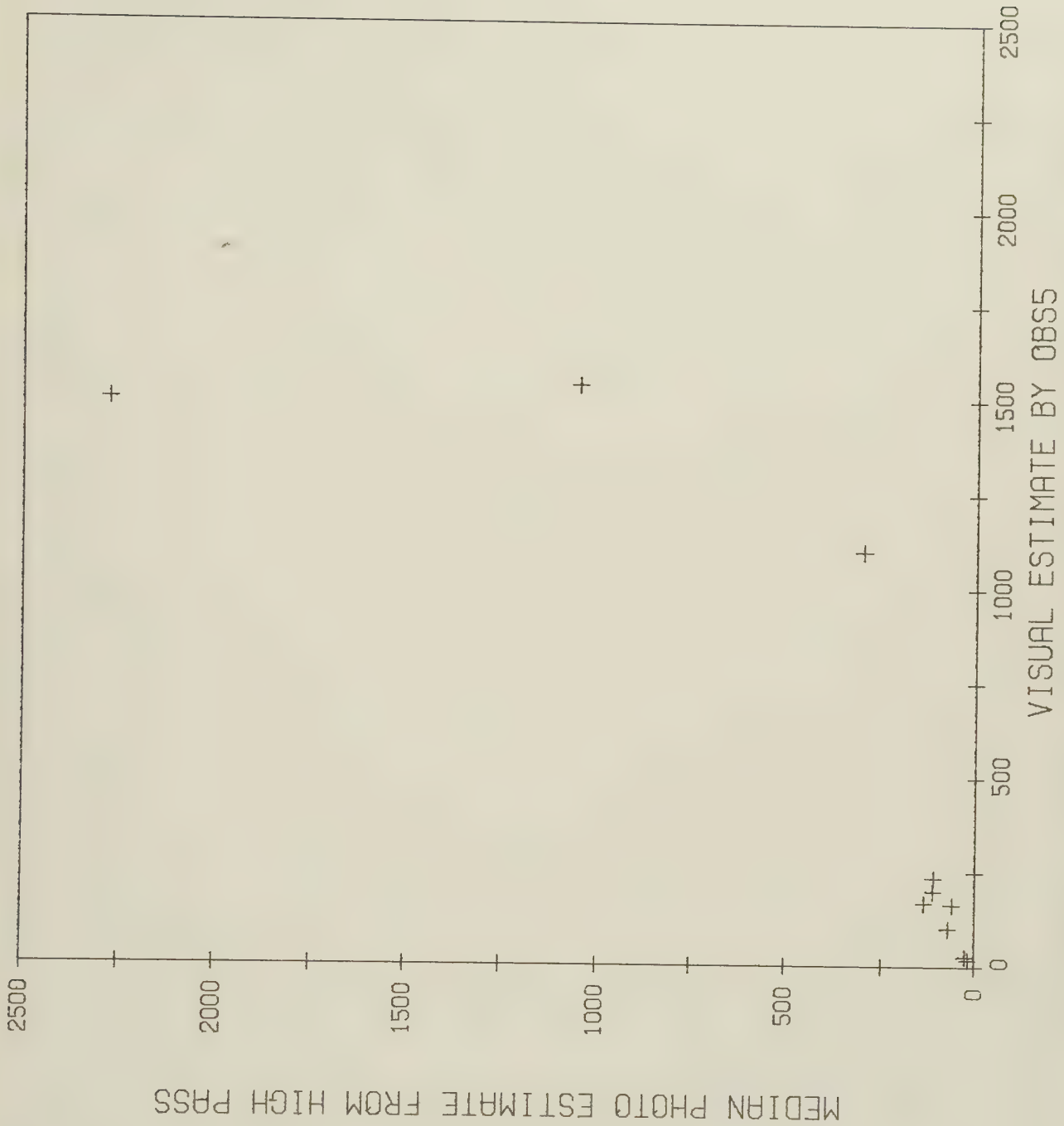


Figure 4. Visual estimates by Observer 5 in 1979 plotted against high median photo estimates.

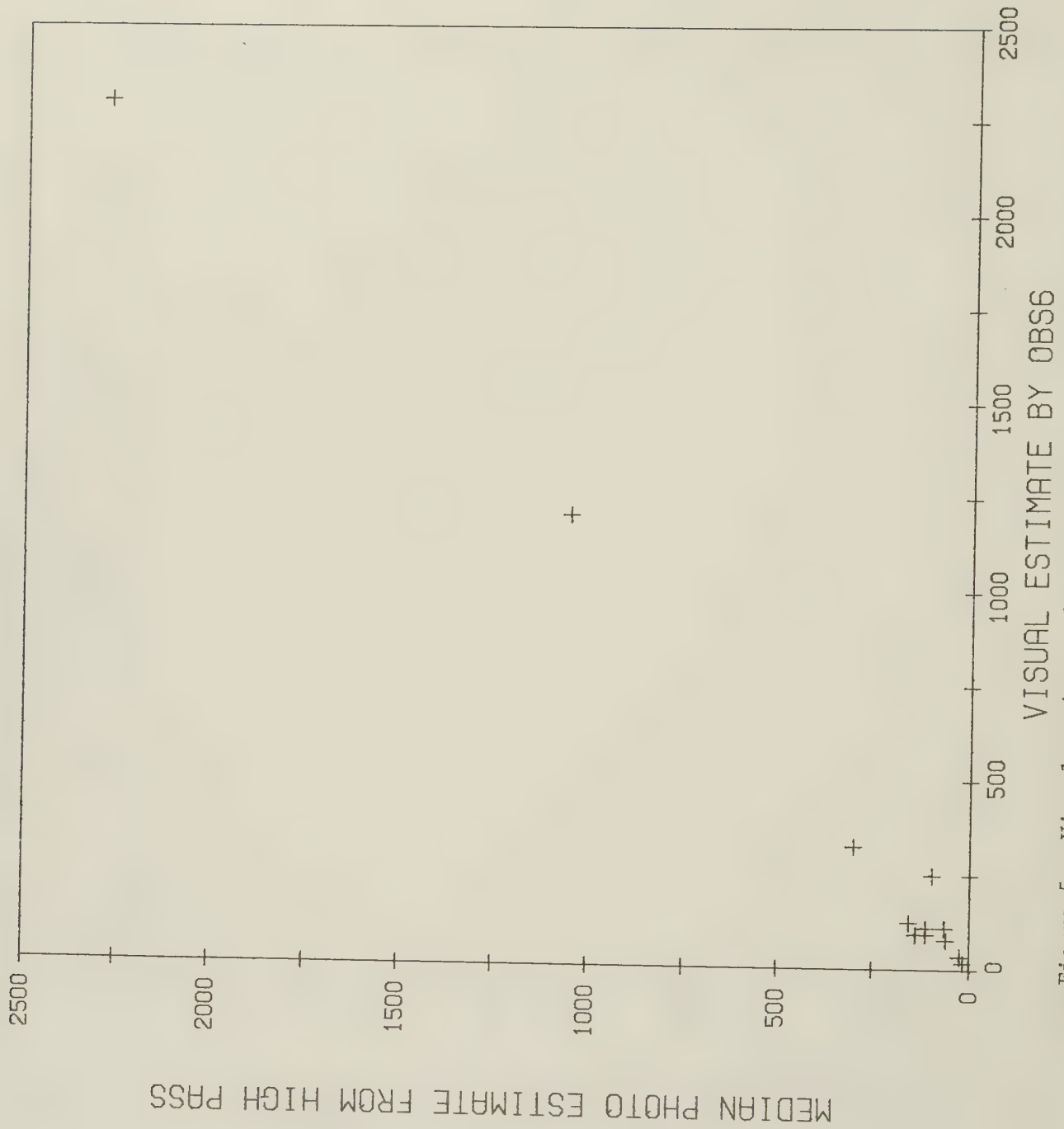


Figure 5. Visual estimates by Observer 6 in 1979 plotted against high median photo estimate.

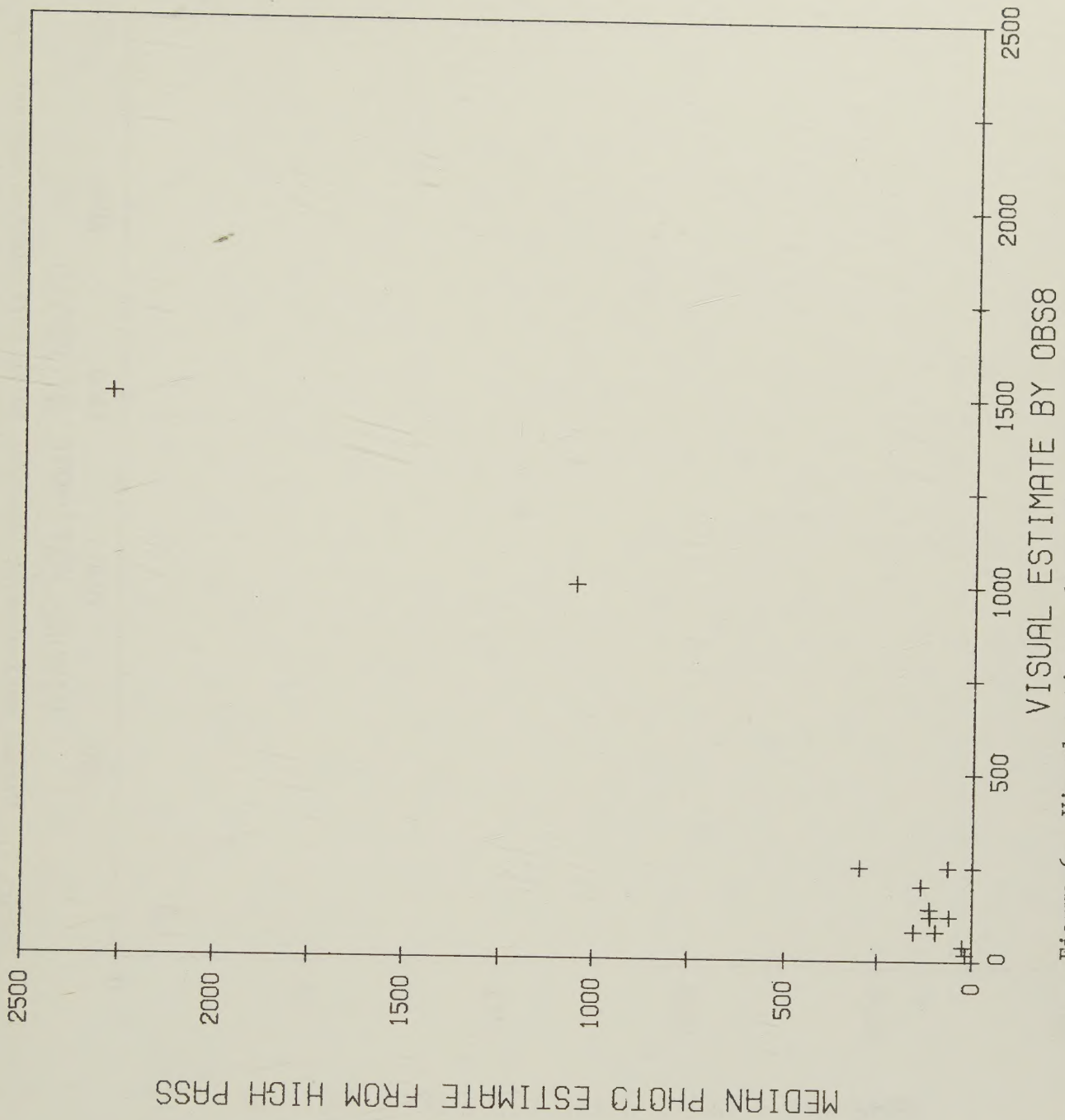


Figure 6. Visual estimates by Observer 8 in 1979 plotted against high median photo estimates.

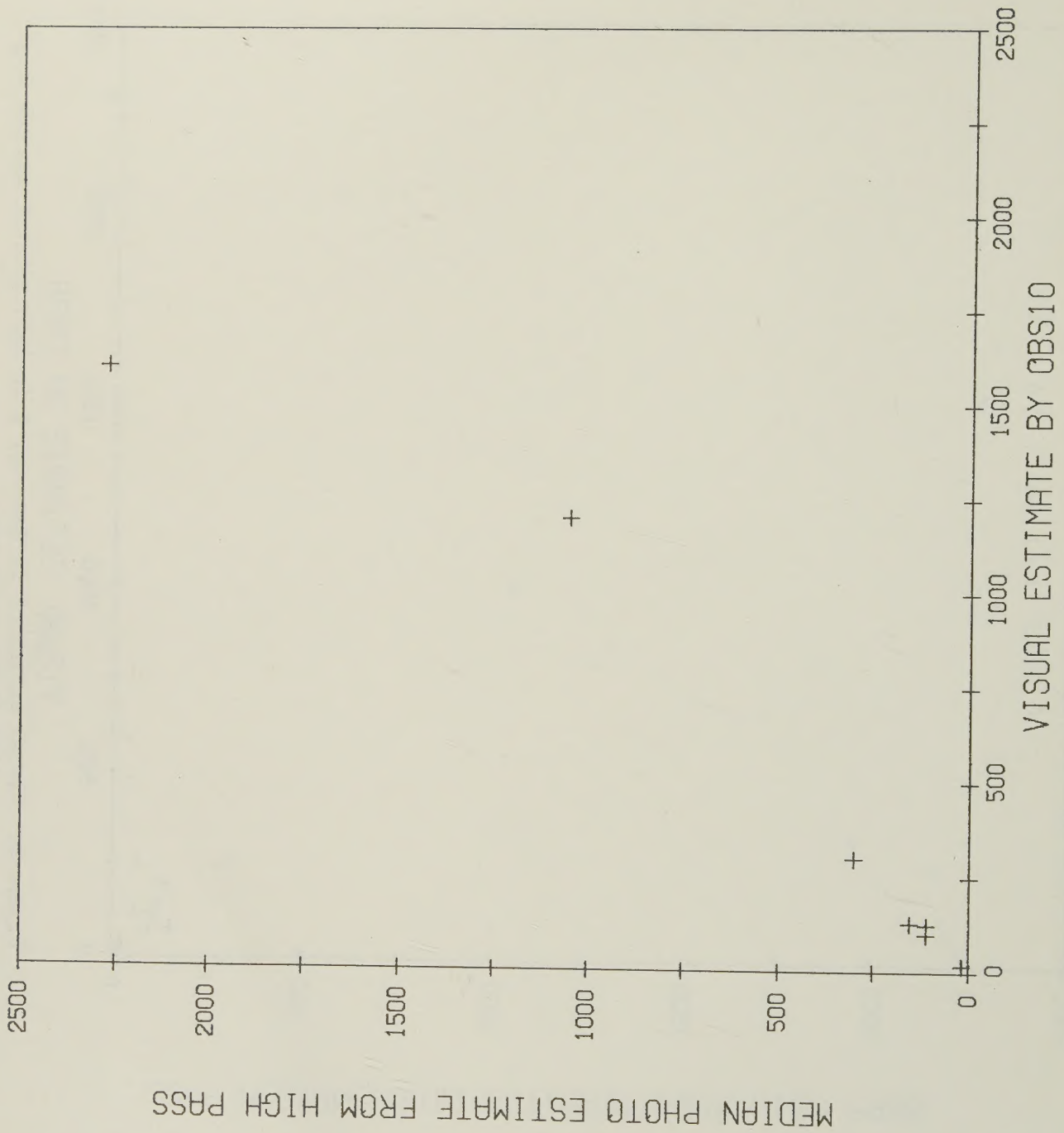


Figure 7. Visual estimates by Observer 10 in 1979 plotted against high median photo estimate.

